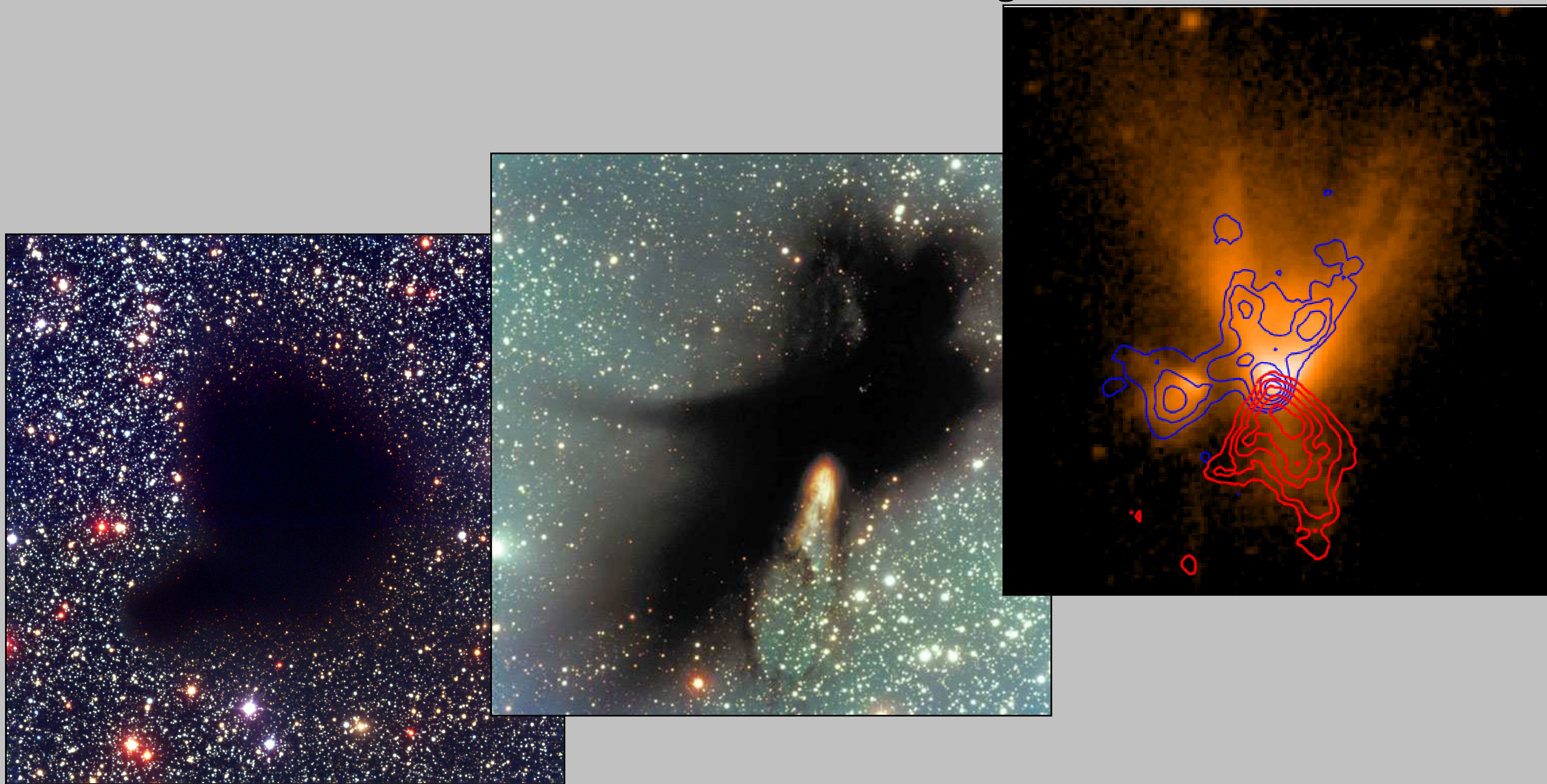
Isolated star formation in Bok globules

or

How simple are the most simple sites of star formation?

R.Launhardt (MPIA Heidelberg)



YLU, March 2004

Ralf Launhardt (MPIA)

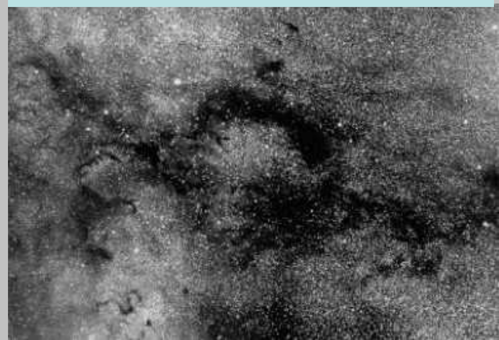
Incomplete list of collaborators

- S. Wolf, T. Khanzadyan, Th. Henning (MPIA)
- R. Zylka (IRAM)
- D. Ward-Thompson (Cardiff)
- T. Bourke (CfA)
- A. Sargent (Caltech)
- H. Zinnecker (AIP)
- Y. Pavlyuchenkov (Moscow)

Why Bok globules?

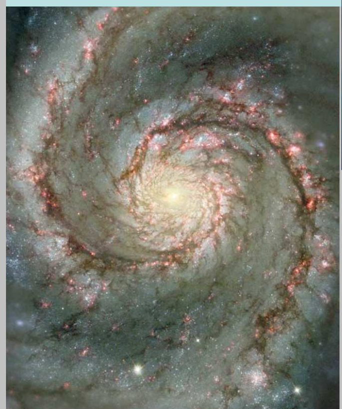
Density profiles, collapse, fragmentation

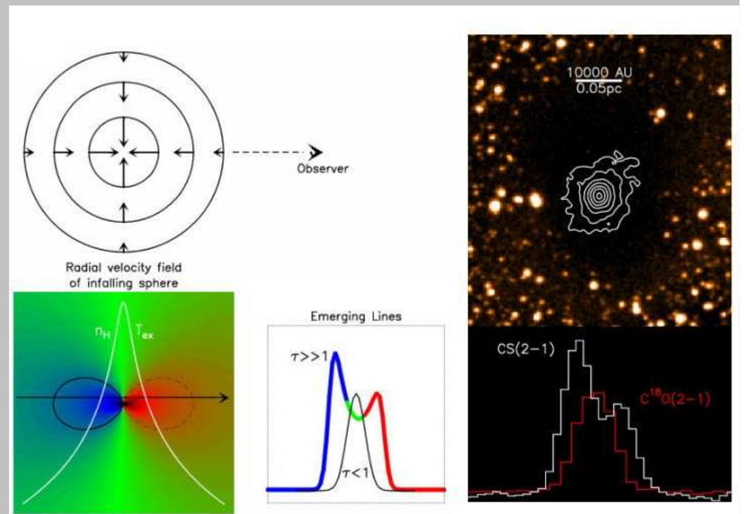
Jets, turbulence, clump mass spectrum



Initial Mass Function

The global view





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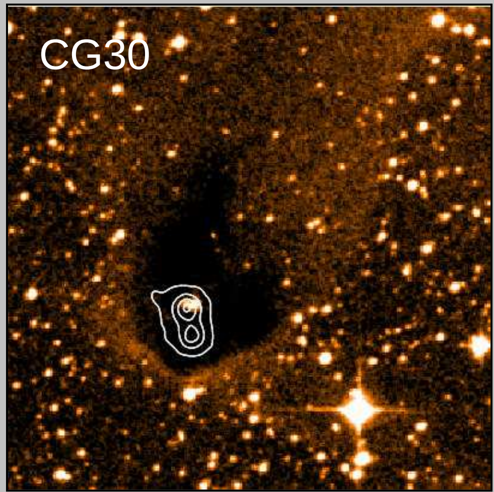
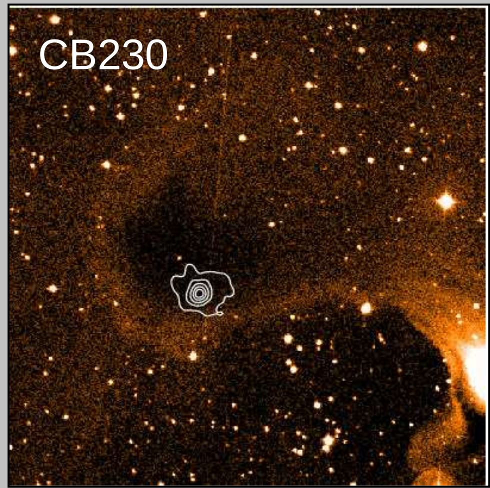
General properties of Bok globules

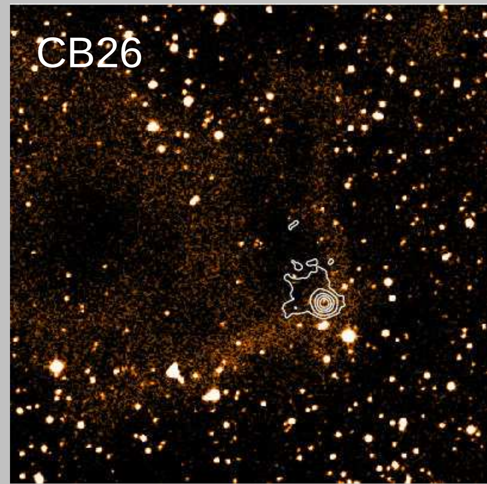
Bok globules are small, very simply structured, relatively isolated molecular clouds.
They resemble dense cores in Taurus (with an envelope).

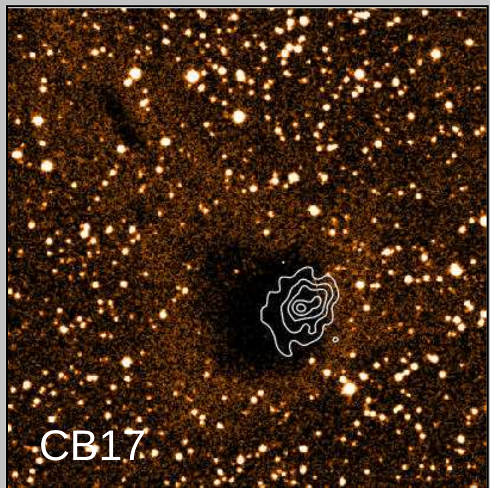
	Globule	Dense core
Mass	5 - 50	1 - 10
Size	0.1 – 2 pc	0.05 pc
Density	(10^3 cm^{-3})	10^6 cm^{-3}
Temperature	(15 K)	10 K
Line widths		0.4 – 0.7 km s^{-1}

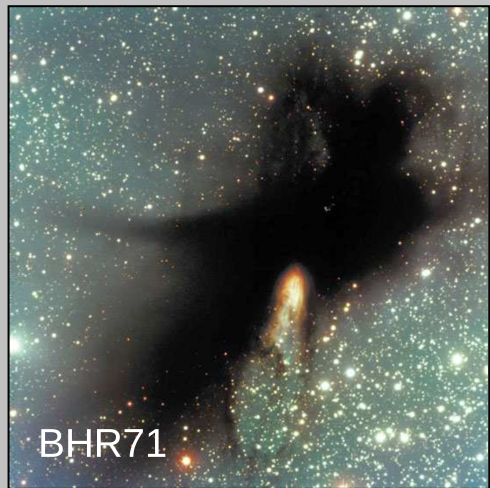
Morphology of Bok globules

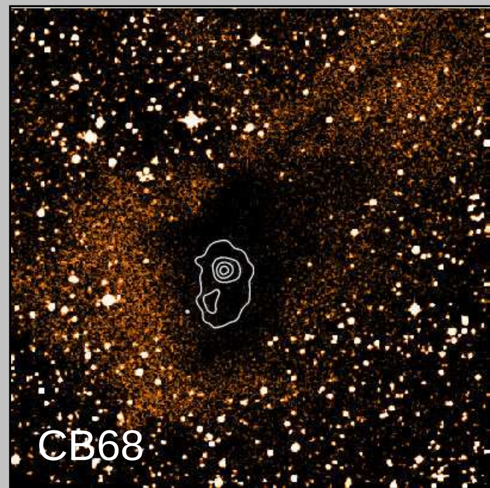








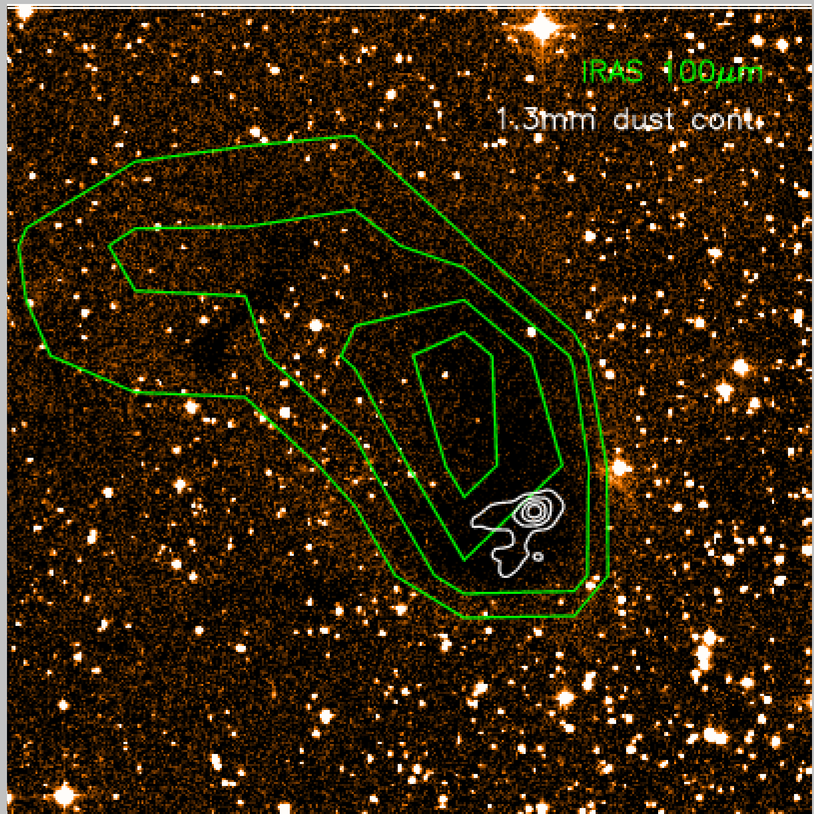


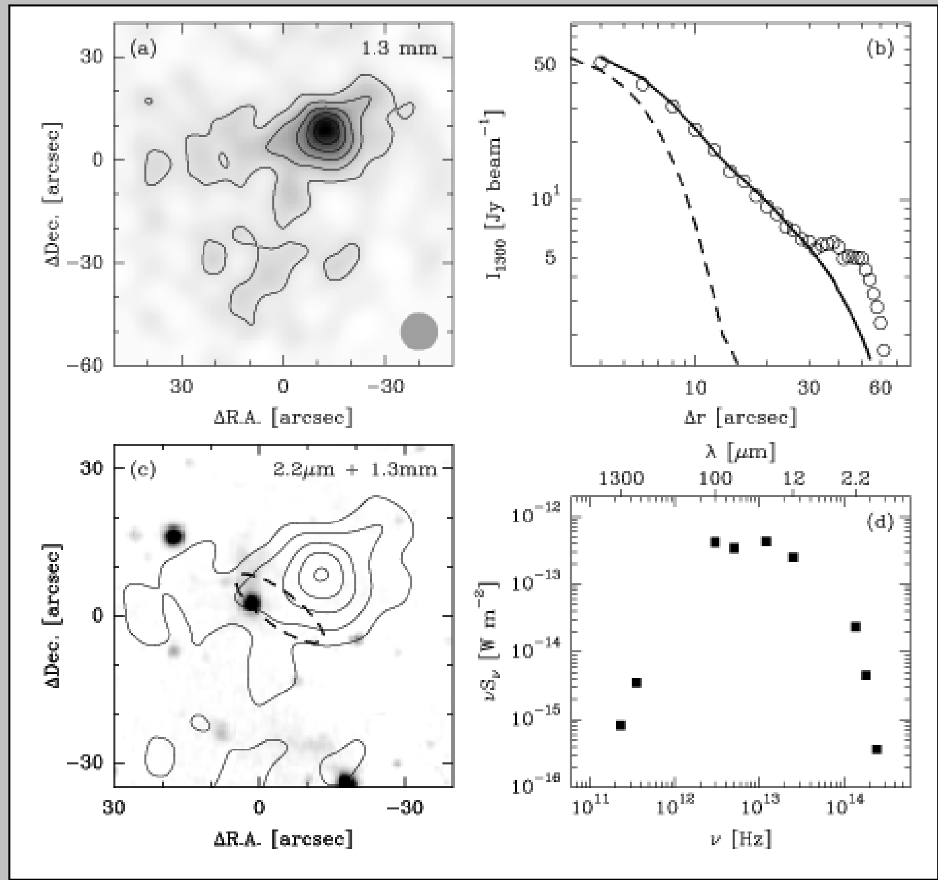


Most globules are cometary or irregularly shaped.
The star-forming cores are often not in the center of the globule.

What do we see when we observe?

Example: CB232





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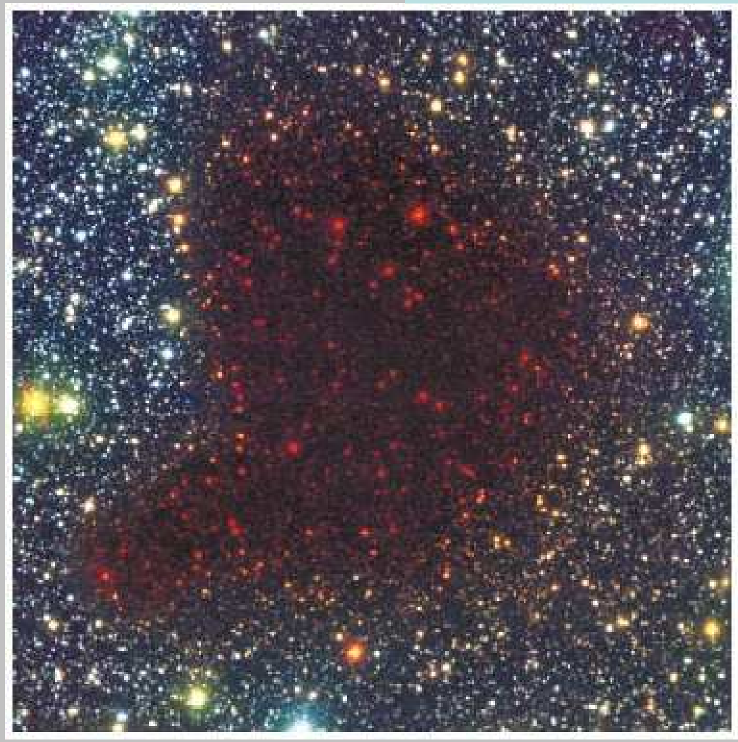
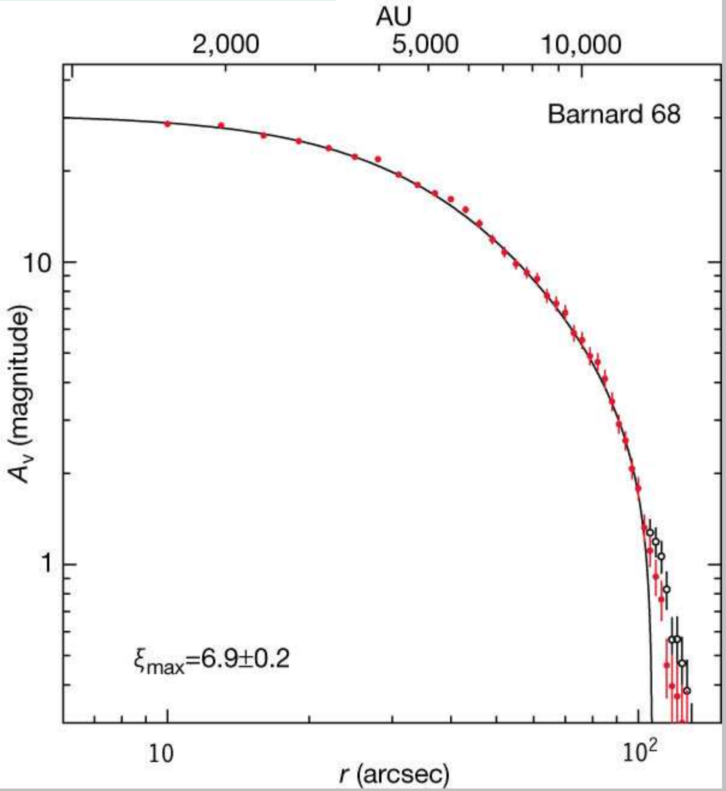
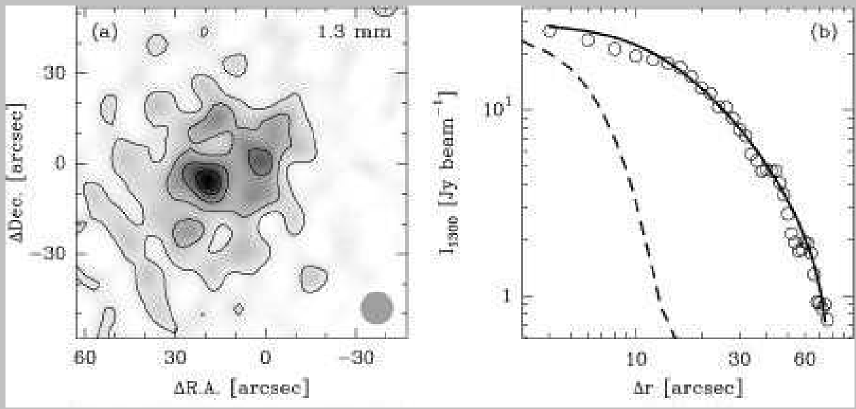
Properties of globules with no star formation

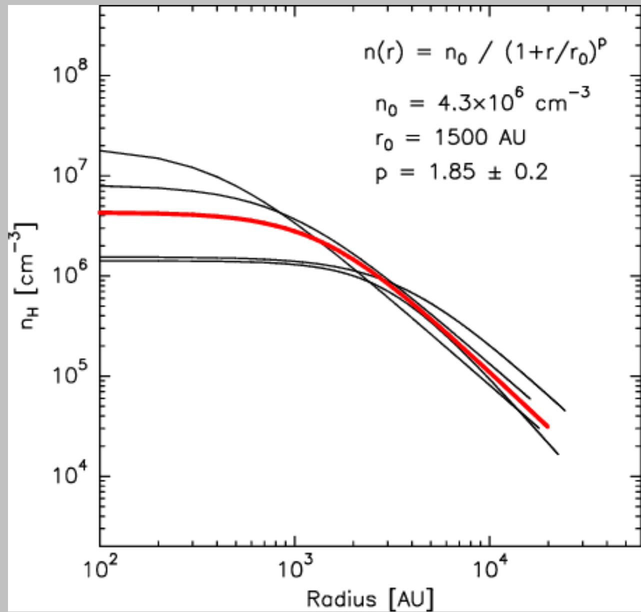
Alves, Lada, & Lada, 2001, nature, 409, 159



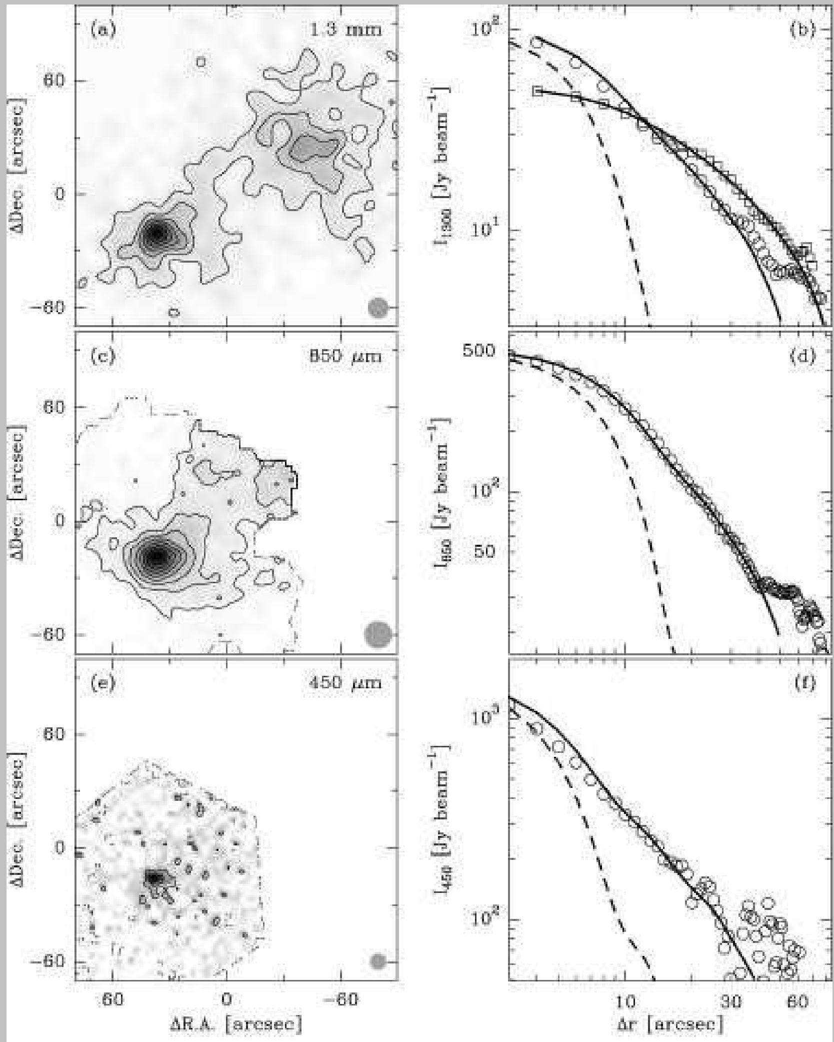


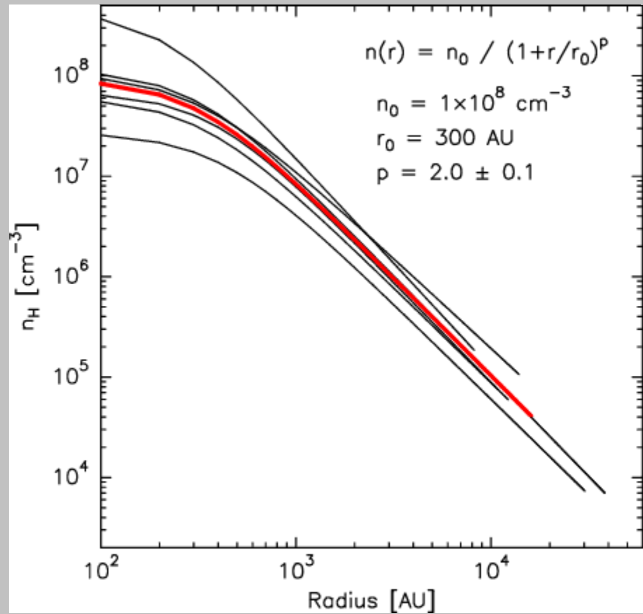
Properties of pre-protostellar cores



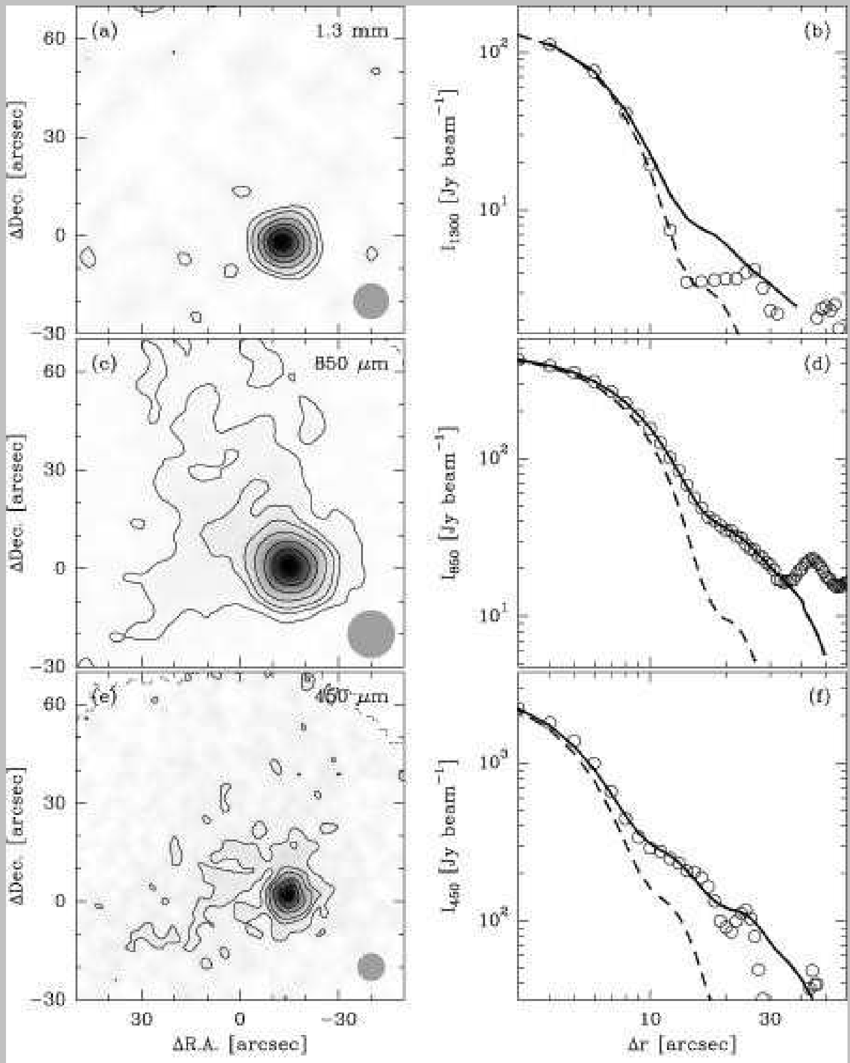


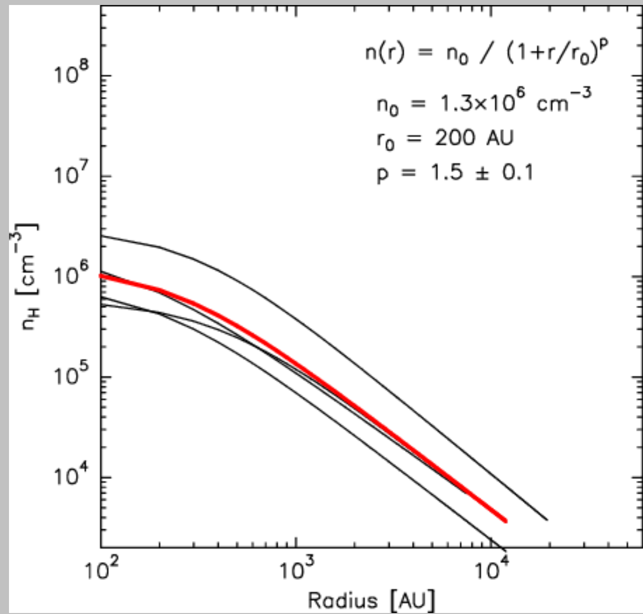
Properties of Class 0 protostellar cores



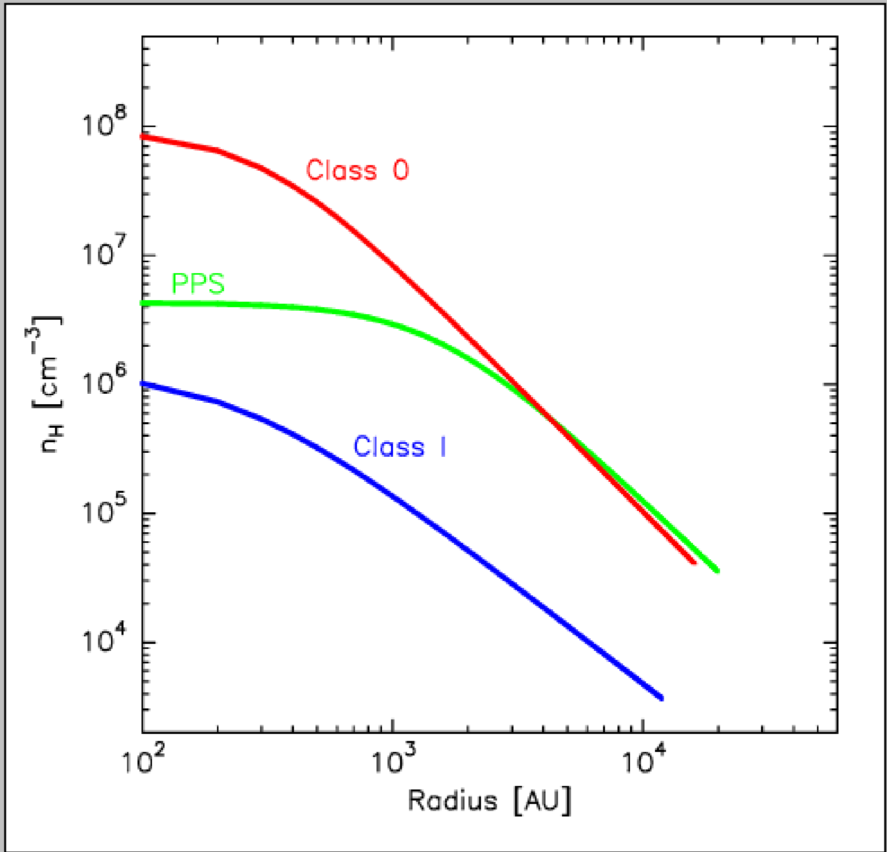


Properties of Class I YSO envelopes





Structure of the star-forming cores



	n_0	r_0	p	M	M_{5000}/M
	[cm^{-3}]	[AU]		[M$_\odot$]	
PPS :	4E6	1500	1.9	5	0.15
Class 0:	1E8	300	2.0	5	0.4
Class I:	1E6	200	1.5	0.1	

$$E_{grav} = -{}^3/_5 \, G \, M^{\,2}/\, R$$

$$\approx 2\text{-}3 \times 10^{36} \text{ Ws}$$

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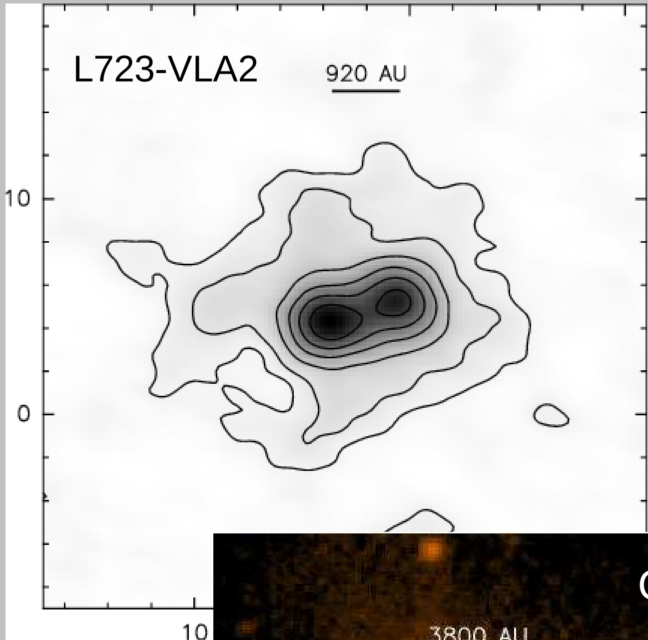
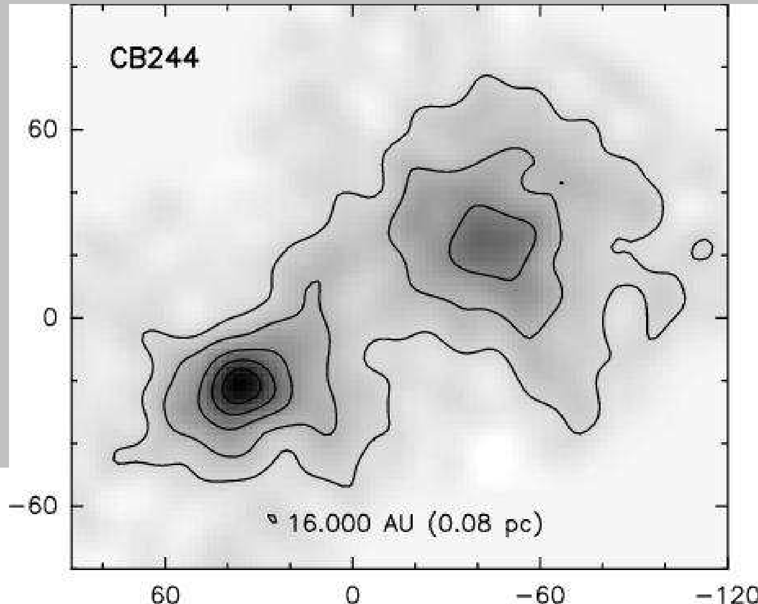
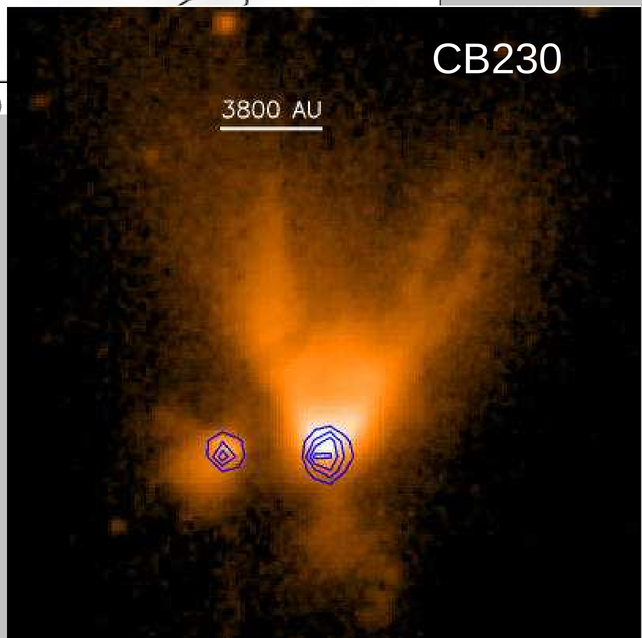
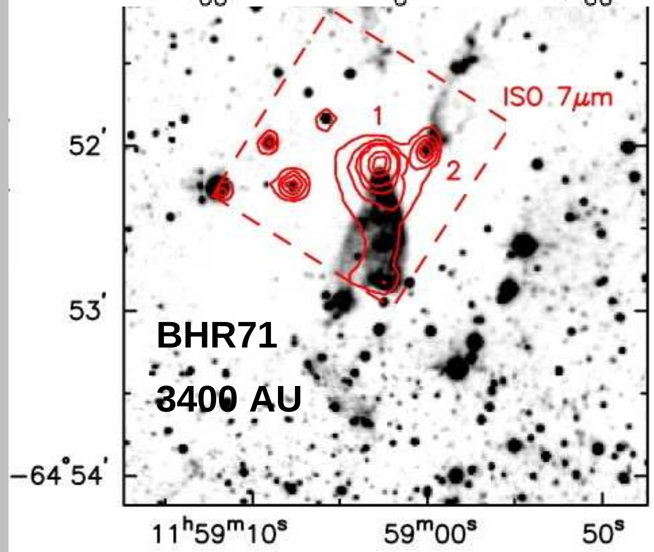
Star formation and Multiplicity

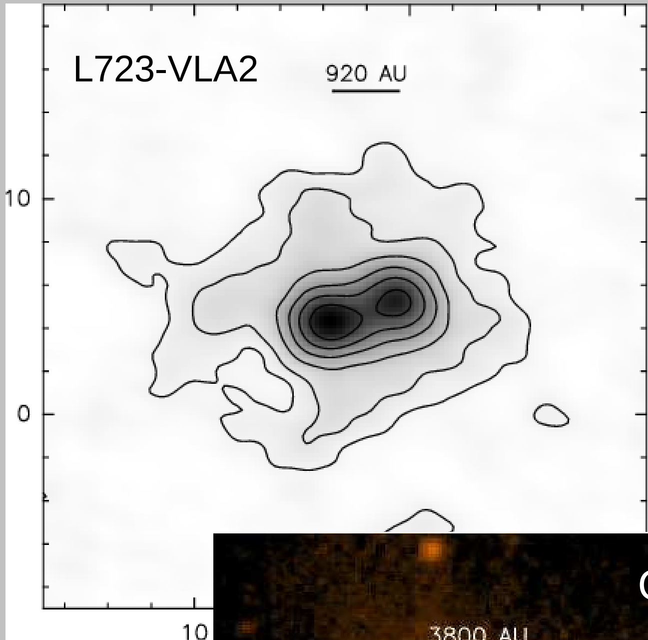


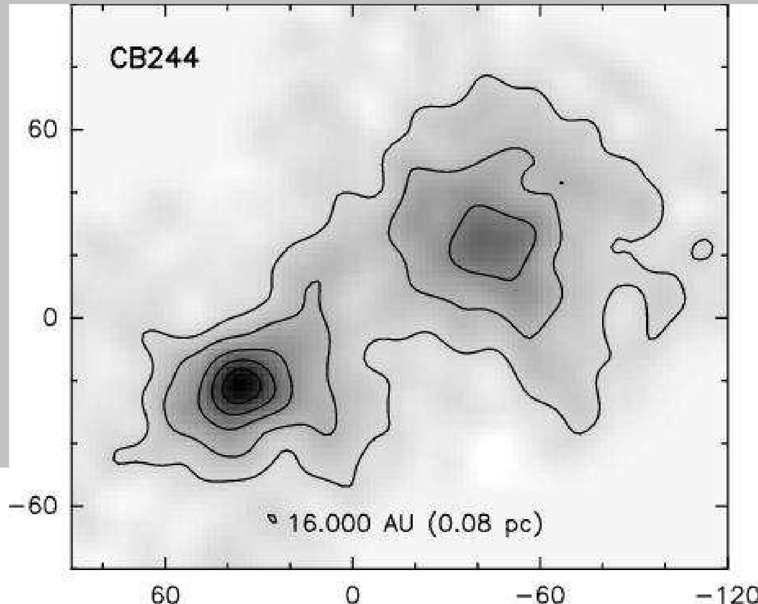


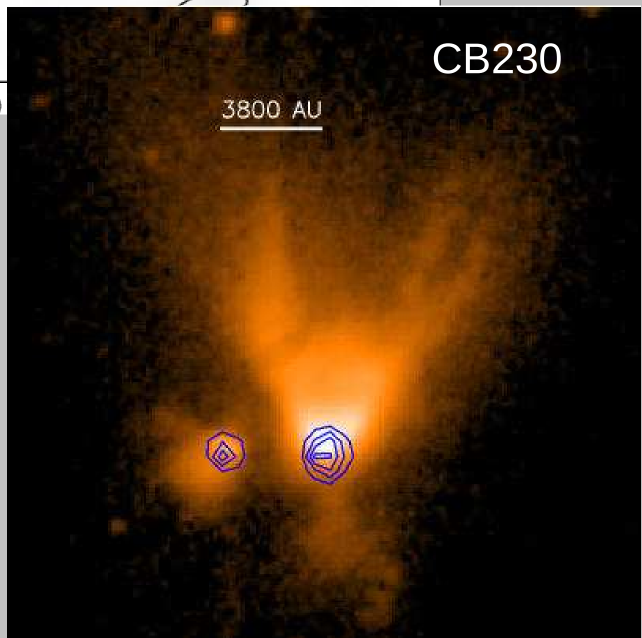


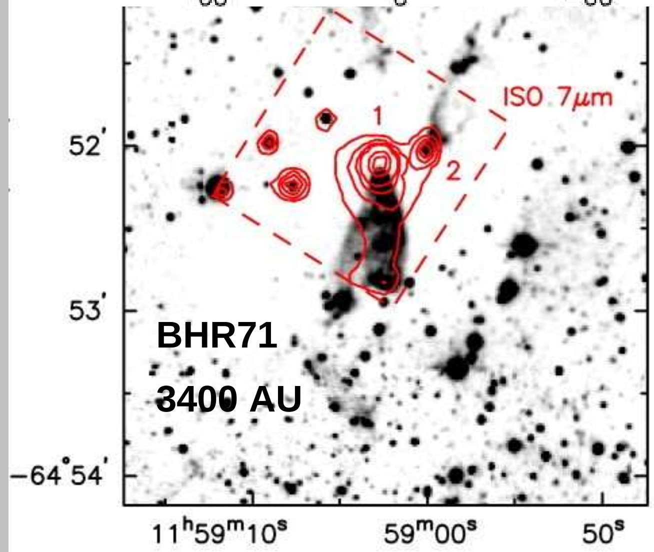


Star formation and Multiplicity





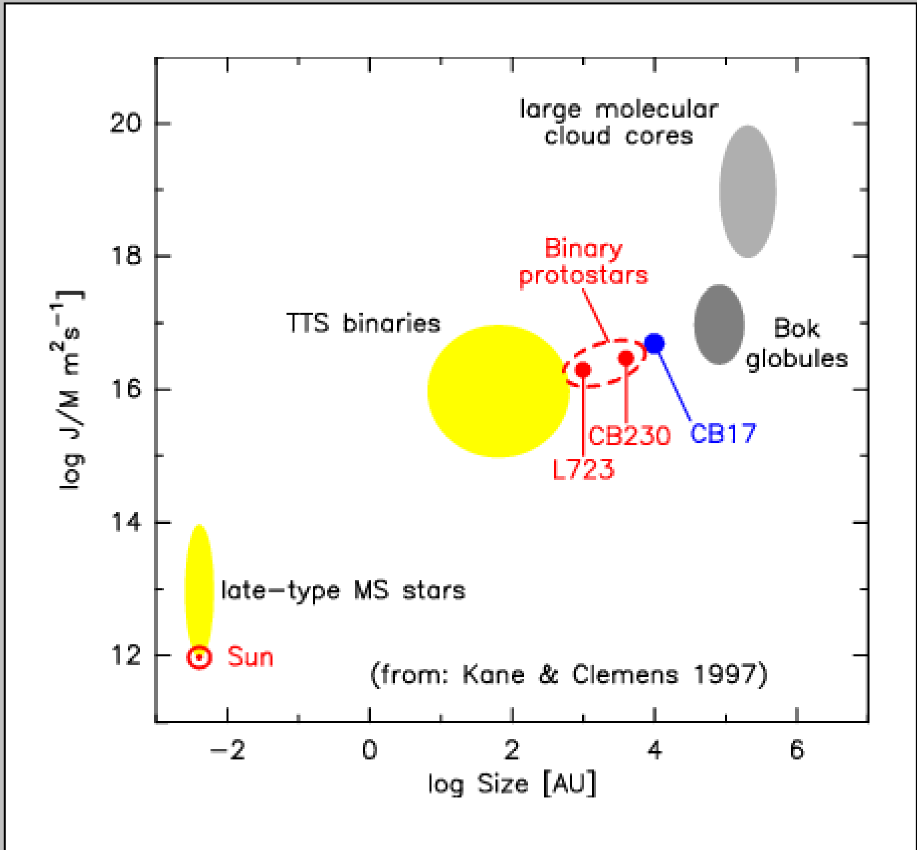


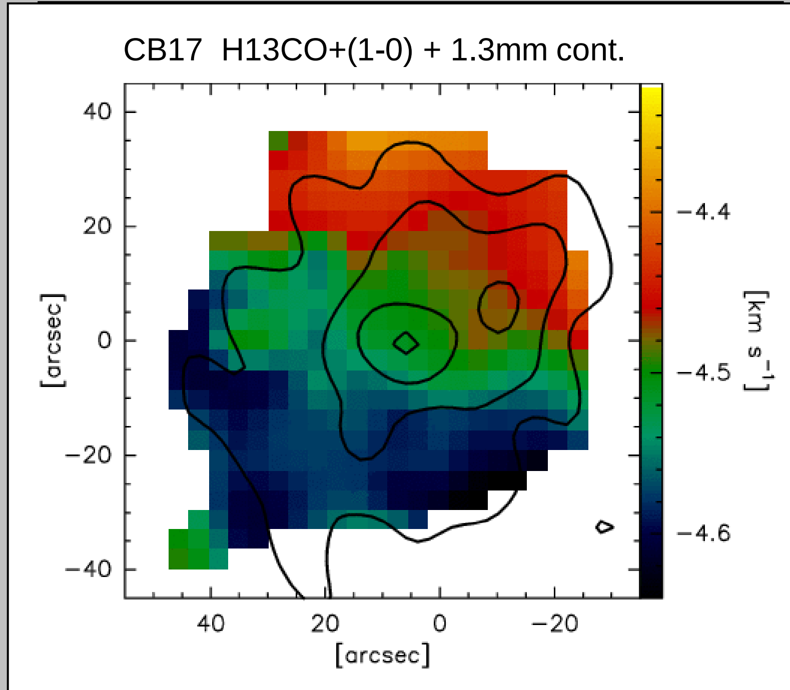


Star formation and Multiplicity

- 78% of star-forming cores in globules are multiple (sample of 23 studied)
- Range of scales: 500 AU - 20.000 AU (0.1 pc)
- → Fragmentation and star formation are inherently coupled, even in simple Bok globules!

Rotation curves and angular momentum





$j = \omega R^2$

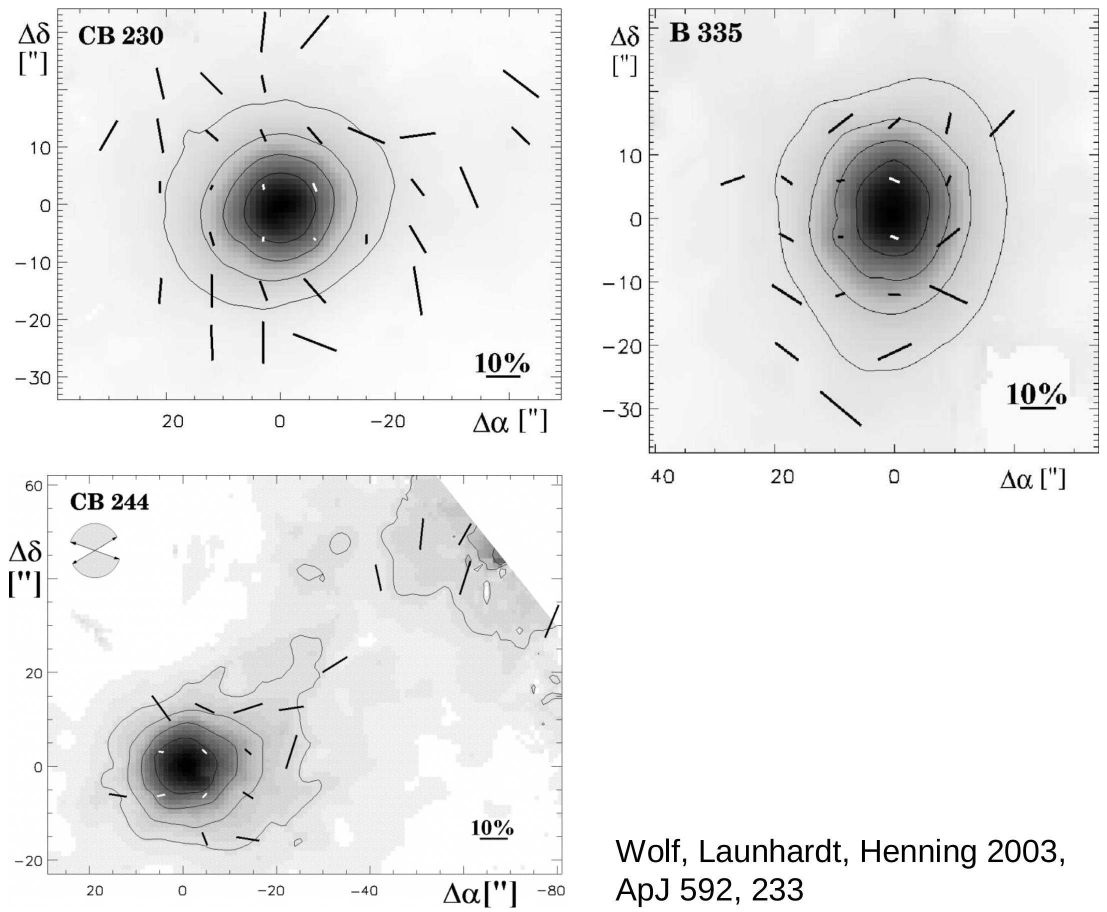
$\approx 2\text{-}9 \times 10^{16}$ m^2 s^{-1}

$E_{rot} = {}^1/_5\, M R^2 \omega^2$

$\approx 4.5 \times 10^{34}$ Ws

Magnetic fields

Submm polarimetric imaging (SCU-POL)



Wolf, Launhardt, Henning 2003, ApJ 592, 233

B field from dispersion of polarization position angles: (Chandrasekhar-Fermi method)

$B \approx 150 \pm 50\ \mu G$

$E_{mag} = {}^{1}/_{6}\, B^2 R^3$

$\approx 1.5 \times 10^{36}$ Ws

Energy balance of the dense cores

$E_{grav} \approx 3 \times 10^{36}$ Ws

$E_{turb} \approx 2 \times 10^{36}$ Ws
$E_{th} \approx 1 \times 10^{36}$ Ws
$E_{mag} \approx 1 \times 10^{36}$ Ws
$E_{rot} \approx 5 \times 10^{34}$ Ws

$$E_{grav} \geq E_{turb} \geq E_{th} \approx E_{mag} >> E_{rot}$$

- Globule cores are close to virial equilibrium
- Main support against gravity is turbulence

Summary & conlcusions

- Bok globules and other isolated cores (e.g., in Taurus) are the most simple sites of (low-mass) star formation
  → physics of collapse, fragmentation, chemical evolution.
- Globules are neither perfectly round nor isolated!
- Globule cores do fragment and form binary/multiple stars.
- Globule cores are near virial equilibrium. Exact energy balance requires hi-res observations and ≥ 2-D modeling.
- Masses: Globule: 5-50 $M_{☼}$ core: 1-10 $M_{☼}$ star: 0.1-1 $M_{☼}$
  → SFE globule: 2% SFE core: 10%
- Many small globules show no signs of star formation
  → undercritical mass? Can they form Brown Dwarfs?